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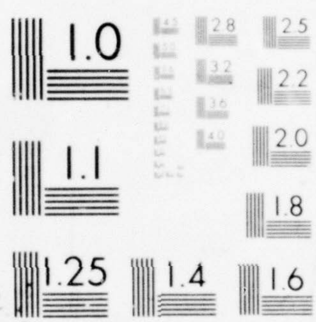

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SOLAR EUV SPECTROPHOTOMETER FOR ATMOSPHERE EXPLORER SATELLITES

Jay L. Buckley
Ball Brothers Research Corporation
P.O. Box 1062
Boulder, Colorado 80306

31 August 1976

Final Report
(October 1971 - June 1976)

Approved for public release; distributing unlimited.

AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Development of the Extreme Ultraviolet Spectrophotometers (EUVS) for the NASA Atmosphere Explorer (AE) mission began October 1971. The Protoflight EUVS was successfully launched December 1973. Flight Units were successfully launched October and November 1974. Technical description and Program history is presented herein.

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SUMMARY

BBRC's contract for the development of the Solar Extreme Ultraviolet Spectrophotometer (EUVS) for Atmosphere Explorer began in October 1971. A Design Verification Unit, a Protoflight Unit and two Flight Units were delivered, with two sets of Ground Support Equipment. The overall Atmosphere Explorer Project was a NASA/Goddard Space Flight Center activity. This contract was supported by NASA under NASA-DPR No. S-50030 AG.

The EUVS consists of twenty-four grating spectrometers that together measure the solar spectrum over the wavelength range 145 Å to 1850 Å. The spectrometer package is roughly cylindrical, twelve inches in diameter by nine inches wide, weighing twenty-two pounds.

This report provides a brief technical description of the EUVS and describes BBRC's activities in the design, fabrication and test of the hardware. Overall, the Protoflight and both Flight Units performed successfully during their orbital missions. Several minor malfunctions are discussed herein.

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ILLUSTRATIONS

1.0 INSTRUMENT DESIGN

This report describes Ball Brothers Research Corporation's development program for the Solar Extreme Ultraviolet Spectrophotometer (EUVS) for the Atmosphere Explorer (AE) satellites. The design conforms to the requirements specified in Contract F19628-72-C-0115 as modified. Reference is made to BBRC drawings for the EUVS, EX 31-B-001 et. seq. for more detail.

1.1 OBJECTIVE

The EUVS is capable of making measurements of the spectral distribuiton of solar intensity in the wavelength range extending from 140 to 1850 Angstroms. The instrument consists of twenty-four monochromators, one half of which record intensities at certain fixed wavelengths. These wavelengths are ones important to studies of atmospheric structure, solar flux variations and to an understanding of mechanisms of dissipation of the input radiant energy. Each of the remaining twelve monochromators scans a limited wavelength range to give, in total, coverage of the 140 to 1850 Angstrom region.

Spectral measurements are made under three different types of orbital conditions or locations as follows: 1) measurements of the incident flux are made over those portions of the orbit which are, for the most part, outside the regions of atmospheric absorption, 2) attenuated flux measurements are made during portions of the orbit which are near or at perigee, and 3) occultation measurements of the attenuated flux are made at times near satellite sunrise and sunset. These measurements provide data on the temporal and spectral character of the Solar EUV flux and the structure of the Earth's upper atmosphere, for correlative studies with data

from other instrumentation aboard the Atmosphere Explorer spacecraft. Figure 1-1 shows the Protoflight EUVS assembled into the Solar Pointing Subsystem. Figures 1-2, 1-3 and 1-4 are internal views of the EUVS.

A portion of the instrument (the "Pointed Section") is mounted on a bi-axial gimbal which maintains the entrance apertures facing the solar direction. This azimuth-elevation table provides the required pointing at the center of the sun with an absolute accuracy of two arcminutes, and can be rastered to other locations on the sun. The azimuth-elevation gimbal is not part of this report except insofar as it is involved in mechanical and electrical interface constraints. It was built by BBRC under subcontract to RCA, the AE Spacecraft prime contractor. In addition to the oriented portion of the EUVS, the Main Electronics Box (MEB) is located internal to the spacecraft.

1.2 SPECTROPHOTOMETRIC PERFORMANCE

The solar-oriented portion of the instrument contains twenty-four monochromators (12 modules) and is capable of making twelve measurements simultaneously. Time-sharing of the photo-detector in each module allows measurements to be recorded for all twenty-four monochromators. Table 1-1 offers a summary of the spectrophotometric requirements of each of the monochromators. Table 1-1a and 1-1b describe the Protoflight EUVS; 1-1c and 1-1d describe the Flight models.

1.2.1 Monochromators

Two basically similar types of monochromators are used in the instrument. One type utilized the positive diffraction orders from a planar grating. The second type used the first negative order of diffraction.

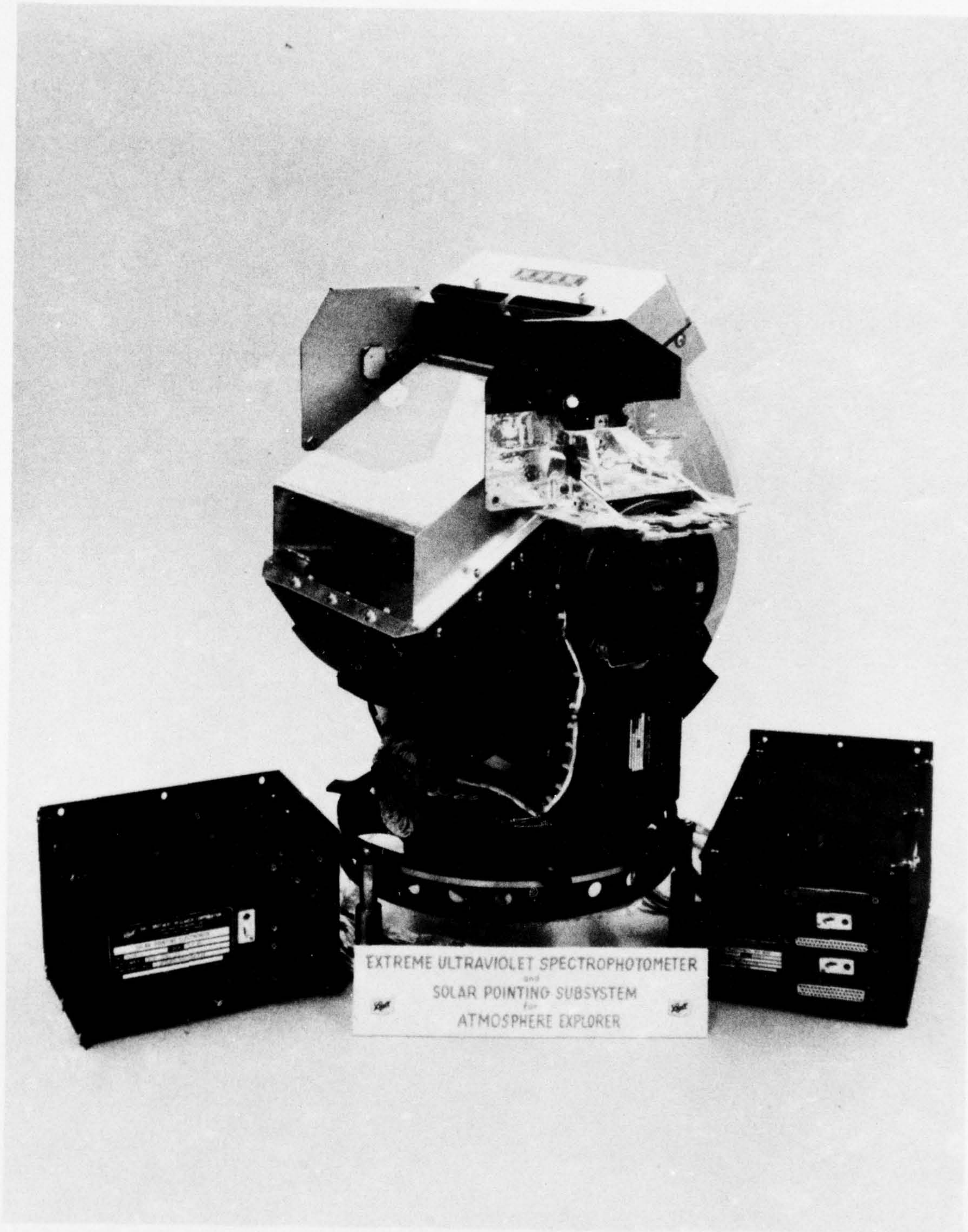

Figure 1-1 Extreme Ultraviolet Spectrometer and Solar Pointing System for Atmosphere Explorer

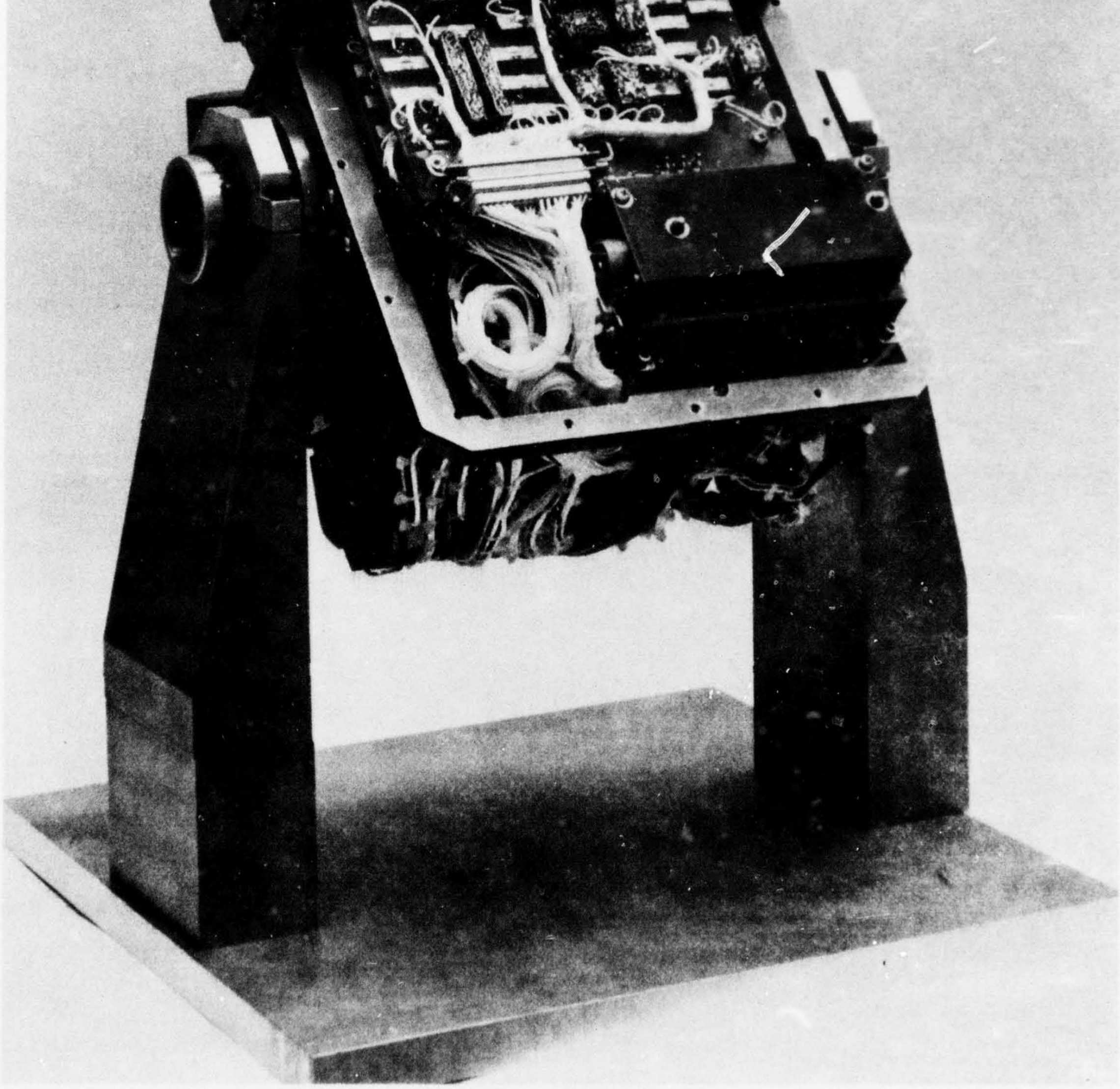

Figure 1-2 Internal Front View of EUVS

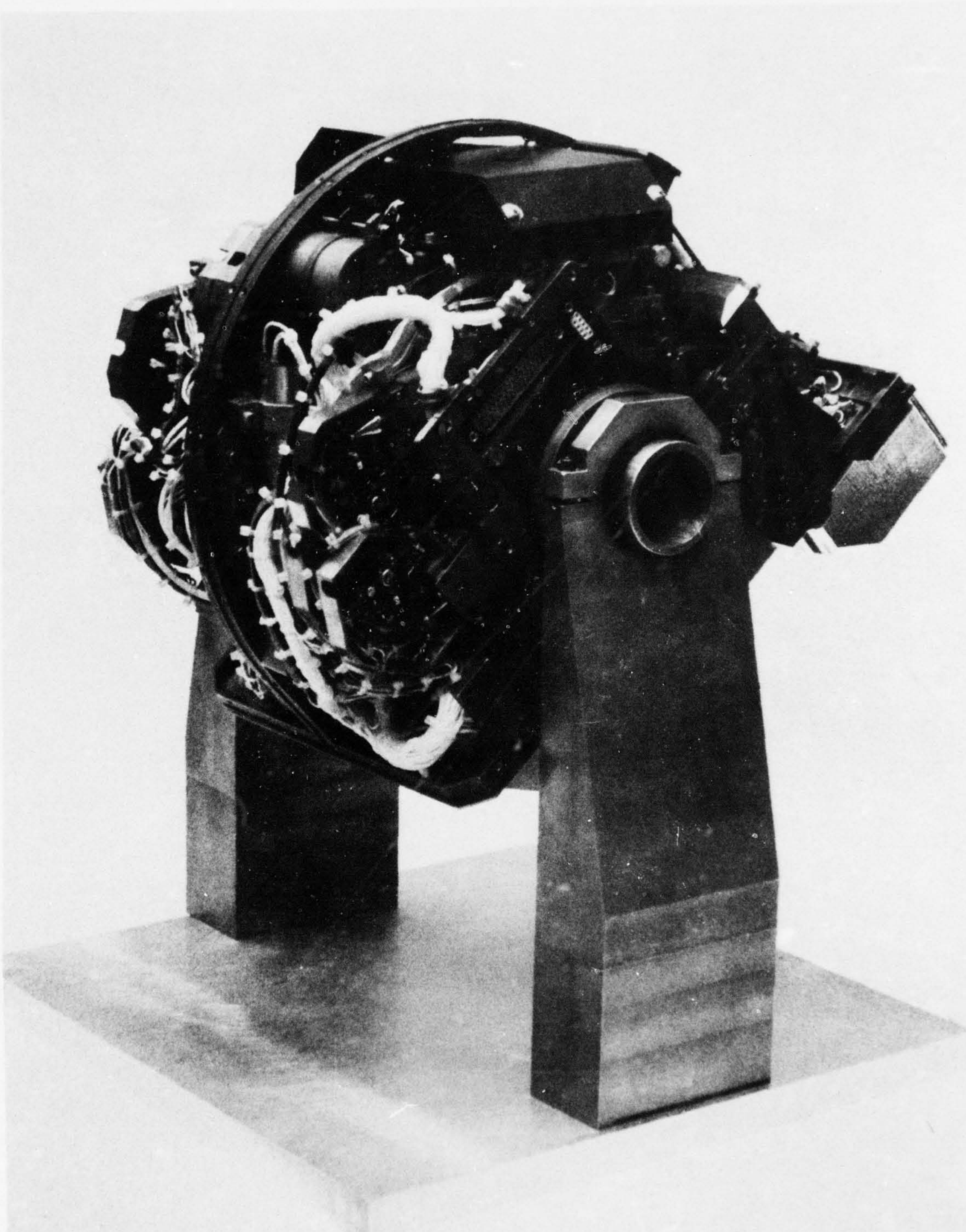

Figure 1-3 Internal Right Side of EUVS

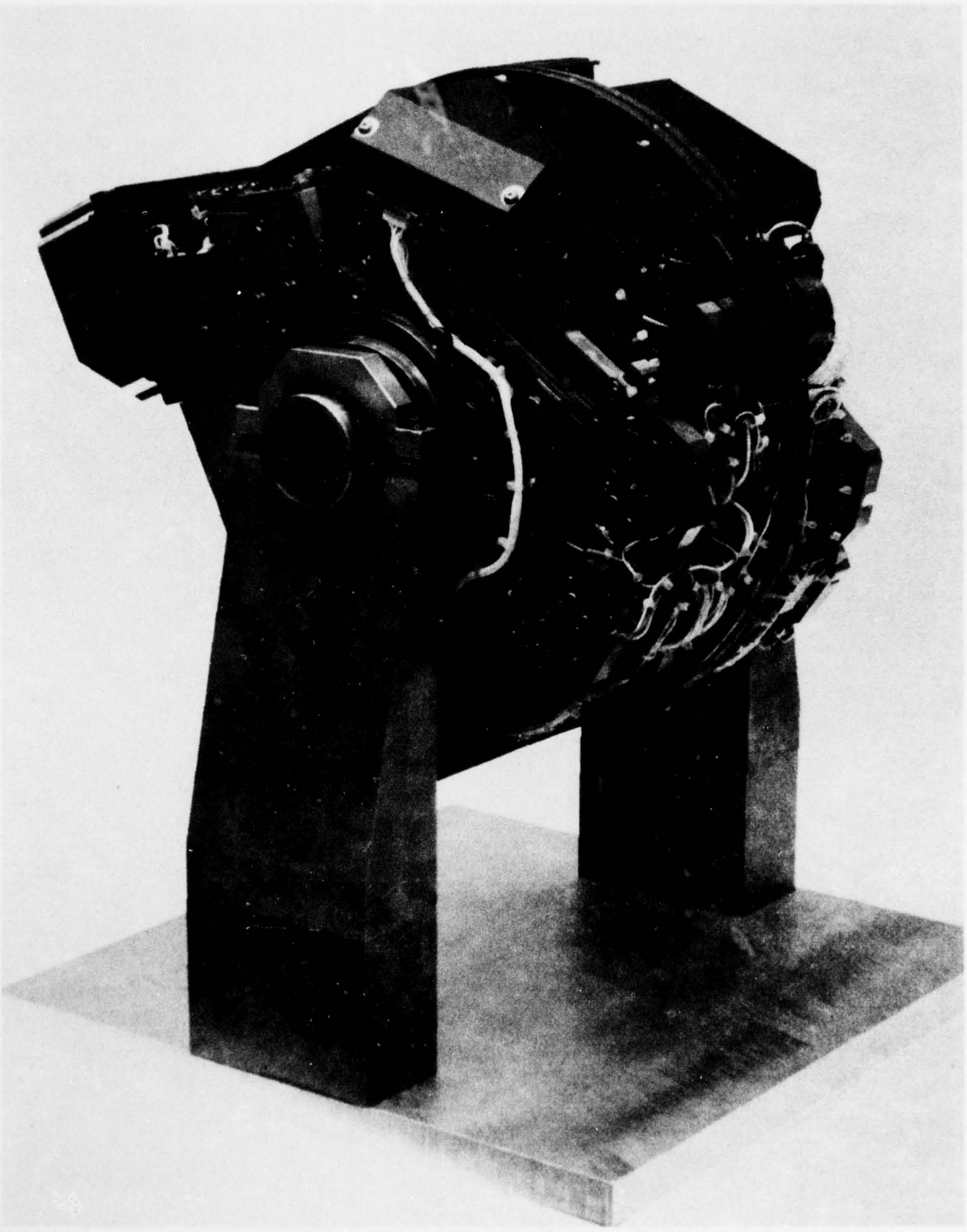

Figure 1-4 Internal Left Side View of EUVS

Table 1-1a

PROTOFLIGHT SCANNING MODULES - NUMBERS 1-6

Module	Aperture	Wavelength Range Å	Grating l/mm	Center of Wavelength Interval	Angle of Incidence	Angle of Diffraction	Field of View	Exit Band Pass Å	Solar Equivalent Å	Spectral Resolution Å	Full Line Width Å	Filter Material	Type of Detector
1	1	142- 208	3600	175	85.71	69.10	$1^o x 1^o$	3.5	1.9	3.5	5.4	None	OPEN CEM
	2	206- 306	2400	256	85.50	69.31	$1^o x 1^o$	1.2	3.0	3.0	4.2	Al	OPEN CEM
2	1	321- 406	3600	363	86.50	60.20	$1^o x 1^o$	3.4	1.4	3.4	4.8	None	OPEN CEM
	2	401- 530	2400	465	84.83	62.17	$1^o x 1^o$	1.7	3.5	3.5	5.2	None	OPEN CEM
3	1	516- 653	3600	584	76.10	49.50	$1^o x 1^o$	10.0	6.2	1.9	5.1	Sn	OPEN CEM
	2	989-1192	2400	1090	79.43	46.17	$1^o x 1^o$	2.1	7.1	7.1	9.2	None	OPEN CEM
4	1	656- 876	2400	765	71.90	50.08	$1^o x 1^o$	4.0	12.0	12.0	16.0	None	OPEN CEM
	2	1256-1696	1200	1475	71.50	50.47	$1^o x 1^o$	26.0	24.6	25.0	50.6	MgF_2	OPEN CEM
5	1	918-1049	3600	983	85.00	39.96	$1^o x 1^o$	1.5	2.3	2.3	3.8	None	OPEN CEM
	2	788- 922	3600	855	81.94	43.03	$1^o x 1^o$	7.1	3.6	7.1	10.7	None	OPEN CEM
6	1	1226-1373	3600	1300	84.19	31.79	6'x6'	5.0	0.5	0.5	5.5	None	PMT
	2	1370-1851	1200	1609	68.49	47.50	6'x6'	14.9	5.3	14.9	20.2	None	PMT

Table 1-1b

PROTOFLIGHT NON-SCANNING MODULES - NUMBERS 7-12

Module	Aperture	Center Wavelength Å	Grating l/mm	Angle of Incidence	Angle of Diffraction	Entrance Field of View	Exit Determined Field of View	Spectral Band Pass	Solar Equivalent Å	Exit Band Pass Å	Filter Material	Type of Detector
7	1	167	3600	69.60	85.85	N/A	10'x6'	11.8	9.0	2.8	Al	OPEN CEM
	2	256	2400	69.42	86.03	N/A	10'x6'	17.9	13.6	4.3	Al	OPEN CEM
8	1	304	3600	62.51	85.21	N/A	6'x6'	14.1	11.9	2.2	Al+C	OPEN CEM
	2	610	1800	62.47	85.25	N/A	6'x16'	28.5	24.0	4.5	Sn	OPEN CEM
9	1	465	2400	62.28	85.44	N/A	10'x12'	23.6	18.0	5.6	None	OPEN CEM
	2	584	1800	62.96	84.76	N/A	10'x8'	30.8	23.5	7.3	Sn	OPEN CEM
10	1	1026	3600	79.93	37.97	N/A	10'x6'	4.7	4.5	0.2	None	OPEN CEM
	2	977	3600	78.89	39.01	N/A	3'x6'	5.2	5.0	0.2	None	OPEN CEM
11	1	1216	900	62.51	85.21	N/A	3'x6'	52.2	47.7	4.5	MgF_2	OPEN CEM
	2	1216	900	62.51	85.31	$1^o x 1^o$	N/A	1[illegible]7.7	47.7	60.0	MgF_2	OPEN CEM
12	1	1600	1200	68.44	47.56	6'x6'	N/A	30.3	5.3	25.0	None	PMT
	2	1775	1200	69.59	46.41	6'x6'	N/A	20.3	5.4	15.2	None	PMT

Table 1-1c

FLIGHT UNIT SCANNING MODULES - NUMBERS 1-6

Module	Aperture	Wavelength Range Å	Grating ℓ/mm	Center of Wavelength Interval	Angle of Incidence	Angle of Diffraction	Field of View	Exit Band Pass Å	Solar Equivalent Å	Spectral Resolution Å	Full Line Width Å	Filter Material	Type of Detector
1	1	142- 208	3600	175	85.71	69.10	$1^o x 1^o$	3.5	1.9	3.5	5.4	None	OPEN CEM
	2	206- 306	2400	256	85.50	69.31	$1^o x 1^o$	1.2	3.0	3.0	4.2	None	OPEN CEM
2	1	321- 406	3600	363	86.50	60.20	$1^o x 1^o$	3.4	1.4	3.4	4.8	None	OPEN CEM
	2	401- 530	2400	465	84.83	62.17	$1^o x 1^o$	1.7	3.5	3.5	5.2	None	OPEN CEM
3	1	516- 653	3600	584	76.10	49.50	$1^o x 1^o$	10.0	6.2	10.0	16.2	Sn	OPEN CEM
	2	989-1192	2400	1090	79.43	46.17	$1^o x 1^o$	2.1	7.1	7.1	9.2	None	OPEN CEM
4	1	656- 876	2400	765	71.90	50.08	$1^o x 1^o$	4.0	12.0	12.0	16.0	20% Mesh	OPEN CEM
	2	1256-1696	1200	1475	71.50	50.47	$1^o x 1^o$	26.0	24.6	25.0	50.6	MgF_2	OPEN CEM
5	1	918-1049	3600	983	85.00	39.96	$1^o x 1^o$	1.5	2.3	2.3	3.8	None	OPEN CEM
	2	788- 922	3600	855	81.94	43.03	$1^o x 1^o$	7.1	3.6	7.1	10.7	None	OPEN CEM
6	1	1226-1373	3600	1300	84.19	31.79	$1^o x 1^o$	1.7	2.6	2.6	4.3	None	PMT
	2	1370-1851	1200	1609	68.49	47.50	6'x6'	14.9	5.3	14.9	20.2	None	PMT

Table 1-1d

FLIGHT UNIT NON-SCANNING MODULES - NUMBERS 7-12

Module	Aperture	Center Wavelength Å	Grating ℓ/mm	Angle of Incidence	Angle of Diffraction	Entrance Field of View	Exit Determined Field of View	Spectral Band Pass	Solar Equivalent Å	Exit Band Pass Å	Filter Material	Type of Detector
7	1	167	3600	69.60	85.85	N/A	10'x6'	11.8	9.0	2.8	None	OPEN CEM
	2	256	2400	69.42	86.03	N/A	10'x6'	17.9	13.6	4.3	None	OPEN CEM
8	1	304	3600	62.51	85.21	N/A	6'x6'	14.1	11.9	2.2	None	OPEN CEM
	2	304	3600	62.51	85.21	N/A	$9' x 1^o$	15.3	11.9	3.4	Al	OPEN CEM
9	1	465	2400	62.28	85.44	N/A	10'x12'	23.6	18.0	5.6	None	OPEN CEM
	2	584	1800	62.96	84.76	N/A	$10' x 1^o$	30.8	23.5	7.3	Sn	OPEN CEM
10	1	1026	3600	79.93	37.97	N/A	10'x6'	4.7	4.5	0.2	None	OPEN CEM
	2	977	3600	78.89	39.01	N/A	3'x6'	5.2	5.0	0.2	None	OPEN CEM
11	1	1216	900	62.51	85.21	N/A	3'x6'	52.2	47.7	4.5	MgF_2	OPEN CEM
	2	1216	900	62.51	85.31	$1^o x 1^o$	N/A	107.7	47.7	60.0	MgF_2	OPEN CEM
12	1	1600	1200	68.44	47.56	6'x6'	N/A	30.3	5.3	25.0	None	PMT
	2	1775	1200	69.59	46.41	6'x6'	N/A	20.3	5.4	15.2	None	PMT

Monochromators working the the positive orders are used in eight of the twelve modules, namely Modules 1-6 and 10 and 12 of Table 1-1.

In the order in which the beam progresses, each positive order monochromator consists of 1) a field-limiting entrance aperture, 2) a planar reflection grating, 3) a concave front-surface mirror to focus, in the plane of dispersion, a parallel bundle of diffracted rays from the grating, 4) an exit slit located at the focus of the mirror, 5) a filter mount to support a thin metallic or crystalline filter in the optical path, and 6) an extreme ultraviolet sensitive photodetector. A system of this type is shown in Figure 1-5. The two reflecting surfaces are illuminated in grazing incidence. Filters are mounted behind the exit slits in a plane normal to the focused beam.

Negative order monochromators are used in four modules, namely 7, 8, 9, and 11 of Table 1-1. These monochromators have the same elements as those working in positive orders with the exception that exit collimation is accomplished without any mirror reflection; that is, by a parallel slit mechanical collimator.

Each of the monochromators of Modules 7-12 (Table 1-1) is configured to look at a single wavelength or wavelength band and is not changed instrumentally. The center wavelengths are realized to within 10% of the spectral band-pass given in Table 1-1.

Each of the monochromators of Modules 1-6 has the capability of scanning a certain wavelength interval as indicated in Table 1-1. Wavelength scanning is achieved by rotation of the monochromator gratings about an axis parallel to the rulings. This axis is located close to the ruled surface near its midpoint. Two independent logic subsystems provide the necessary timing and driving pulses.

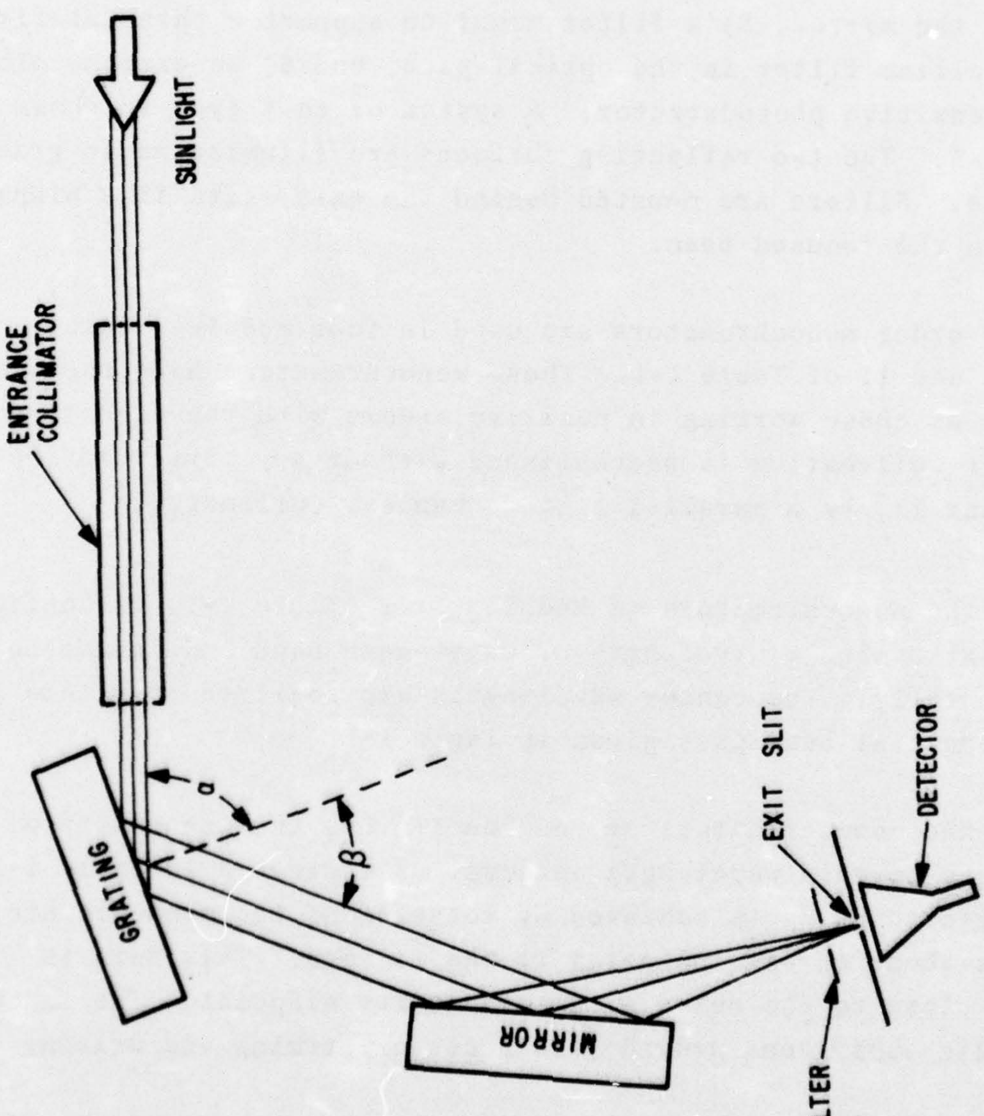

Figure 1-5 Typical Monochromator

Step positions are encoded by a mechanical shaft-angle encoder and telemetered once each 0.5 of a second. Scanning is accomplished by coupling the scan grating box to a precision cam through an arm and cam follower. Rotation of the cam by one step (2.8125 degrees) rotates the gratings by 1.50 arc minutes. The cam has a stow position incorporated so that the grating boxes are held captive during launch.

1.2.2 Gratings

All monochromator gratings except 6-2 and 12-1 are gold-coated replicas appropriately selected for high first-order reflectivity, high first-to-higher order ratios and low levels of scattered light. Monochromators 6-2 and 12-1 use aluminum-coated gratings. The required values of grating constant are indicated in Table 1-1. Gratings used in this instrument are made on blanks of identical size, with sufficiently precise squaring and facing so that all blanks are interchangeable in any of the monochromator structures (ref. BBRC drawing 40411). To the extent possible, all replicas are blazed for high first-order reflectivity for the particular wavelength region for which they are to be used. A typical grating is shown in Figure 1-6. The gratings were procured from Bausch and Lomb, Rochester, N.Y. Several 3600 ℓ/mm holographic gratings were procured from Jobin Yvon Optical Systems, Paris, France. These were calibrated but not flown.

1.2.3 Mirrors

The concave mirrors used in the positive monochromators are off-axis parabolic sections in the focal direction, and flat in the cross-focus direction. The mirrors are replicated in gold from a convex master onto machined magnesium substrates. Following

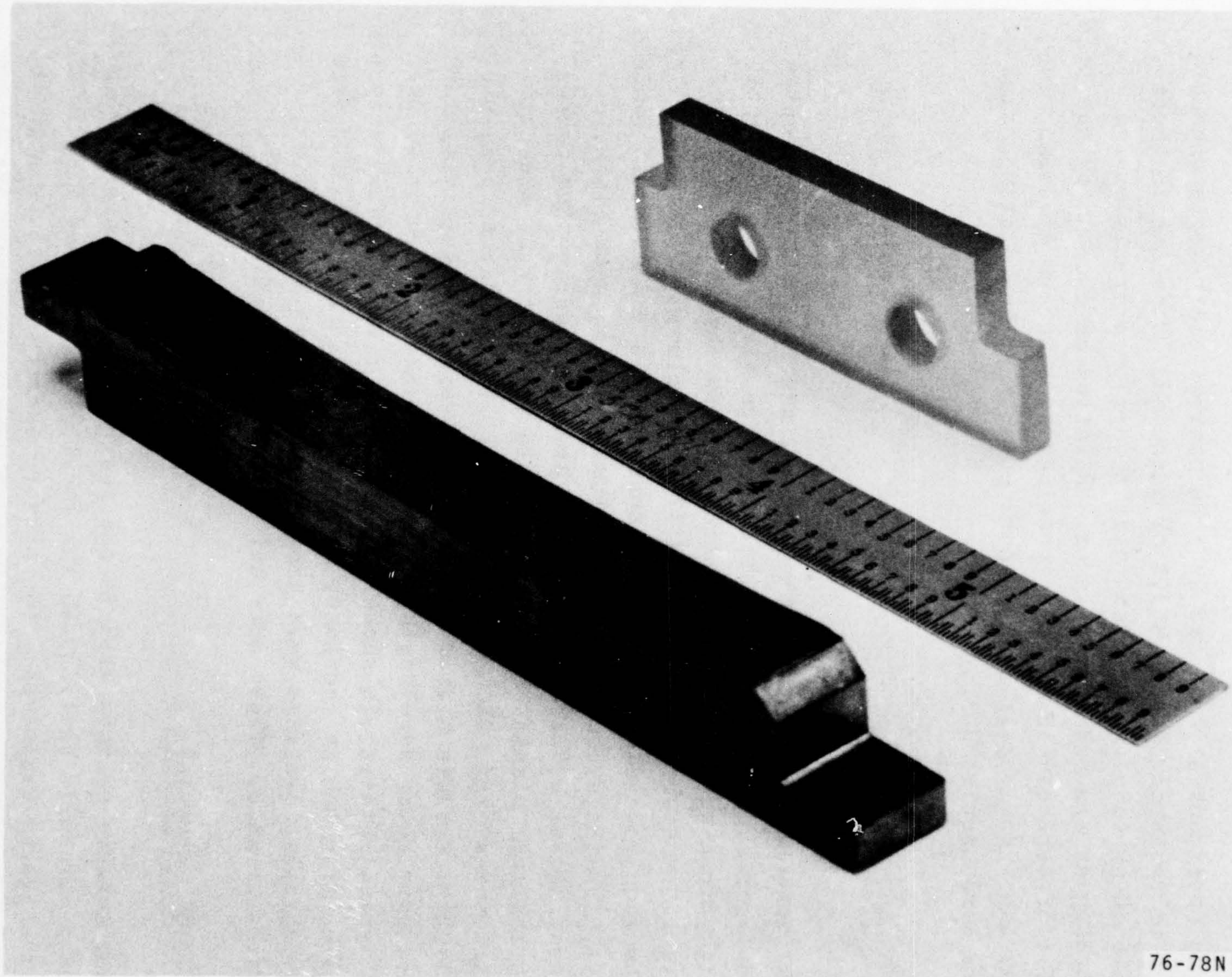

Figure 1-6 Grating and Mirror

replication and final trim machining, a second layer of gold is evaporated onto the replicated gold surface. A typical mirror is shown in Figure 1-6. BBRC drawing 40405 provides a more detailed description of the mirror. The mirrors were procured from Perkin-Elmer, Costa Mesa, California.

1.2.4 Filters

Thin metallic or crystalline filters are mounted normal to the exit beams on suitable support structures located immediately behind the exit slits. The filter frames actually mount to the CEM detector housings, to allow easy access. Metal filters are made of films of highest chemical purity which are as pin-hole free as possible. Pin-hole transmission are generally 10^{-4} to 10^{-6} or smaller. The films are supported by 70 line per inch mesh, with transparency of 80%. Specific filter materials are listed in Table 1-1. The EUVS mechanical design allows for filters in all monochromators. The filters were procurred from Luxel Corporation, Santa Barbara, California.

1.2.5 Detectors

Modules 6 and 12 use sealed photomultiplier detectors with high efficiency in the range 1300 - 1850 Å and low sensitivity to longer wavelengths (extreme-solar-blind). These detectors are EMR 641-G-09-18, with CsI cathode and MgF_2 window, packaged to fit EUVS constraints (Figure 1-7).

Detectors for Modules 1-5 and 7-11 are identical-type CEMs, with aperture area (cone) large enough to accept the optical beams from the two monochromators of each module. CEM configuration is determined in part by packaging compatibility within the EUVS. The configuration is that of the Galileo (Bendix) CEM 4019: a 45° full-angle cone followed by a C-shaped multiplier section. The actual CEM is a modification of the 4019 that included 3 mm cylindrical extension in front of the cone.

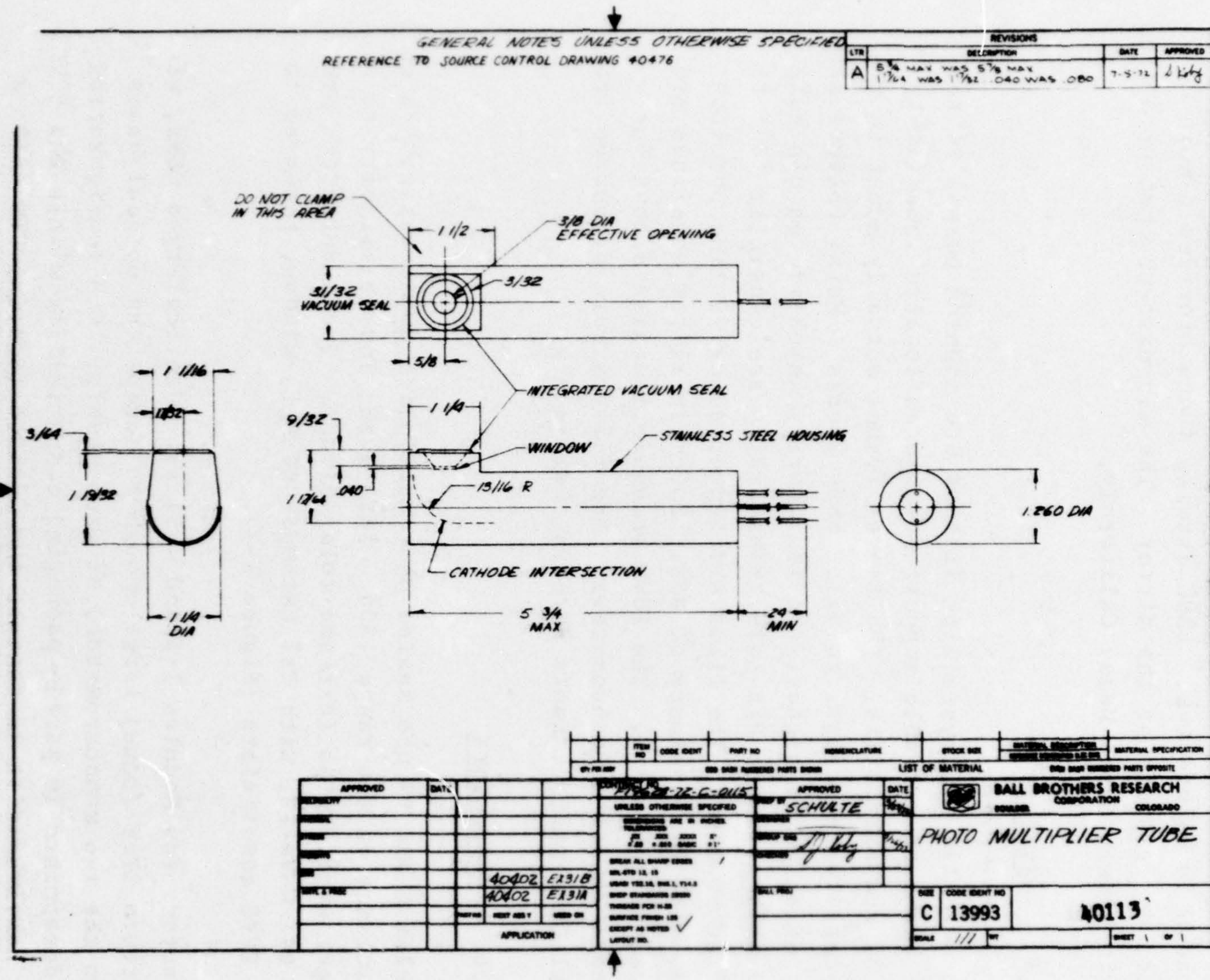

Figure 1-7 Photomultiplier Tube

The multipliers are mounted in a configuration which assures their survival through launch stresses but also does not contribute, through outgassing, to deterioration of multiplier characteristics. The detectors are mounted by three fiberglass standoffs to a fiberglass printed circuit board (Figure 1-8). The PC board contains the pre-amplifier and blocking and filter capacitors for the CEM. The three point mounting provides good mechanical support, allows free flexure to compensate for thermal stresses, and avoids the CEM/potting interface problems associated with solid mounts.

1.2.6 Alignment and Calibration

Each of the EUVS modules is individually aligned on a test fixture. For the fixed modules, coarsely ruled gratings are used so that visible light can pass through the modules from end to end. The scan modules are aligned on an element-by-element basis, then checked with coarse gratings in the scan grating boxes.

The modules are then installed in the structure, and aligned to the reference mirror surface on the front of the structure. After optical alignment, the coarse gratings are replaced with Flight UV gratings, and filters and detectors are installed. Final alignment check is combined with photometric calibration testing using UV radiation in vacuum.

The source for these tests is an modified Hinteregger-type flowing gas discharge lamp, with a 1 mm diameter aperture located 1300 mm from the face of the instrument. With this source, emissions from He, H_2, and Ne are used to check 21 of the 24 monochromators.

The instrument is mounted on a two-stage stand that allows tilt adjustment (epsilon) and lateral translation (gamma). Fields-of-view and spectral scans are made for each of the 21 monochromators. Results are examined for alignment, vignetting, scattered light levels, and signal levels.

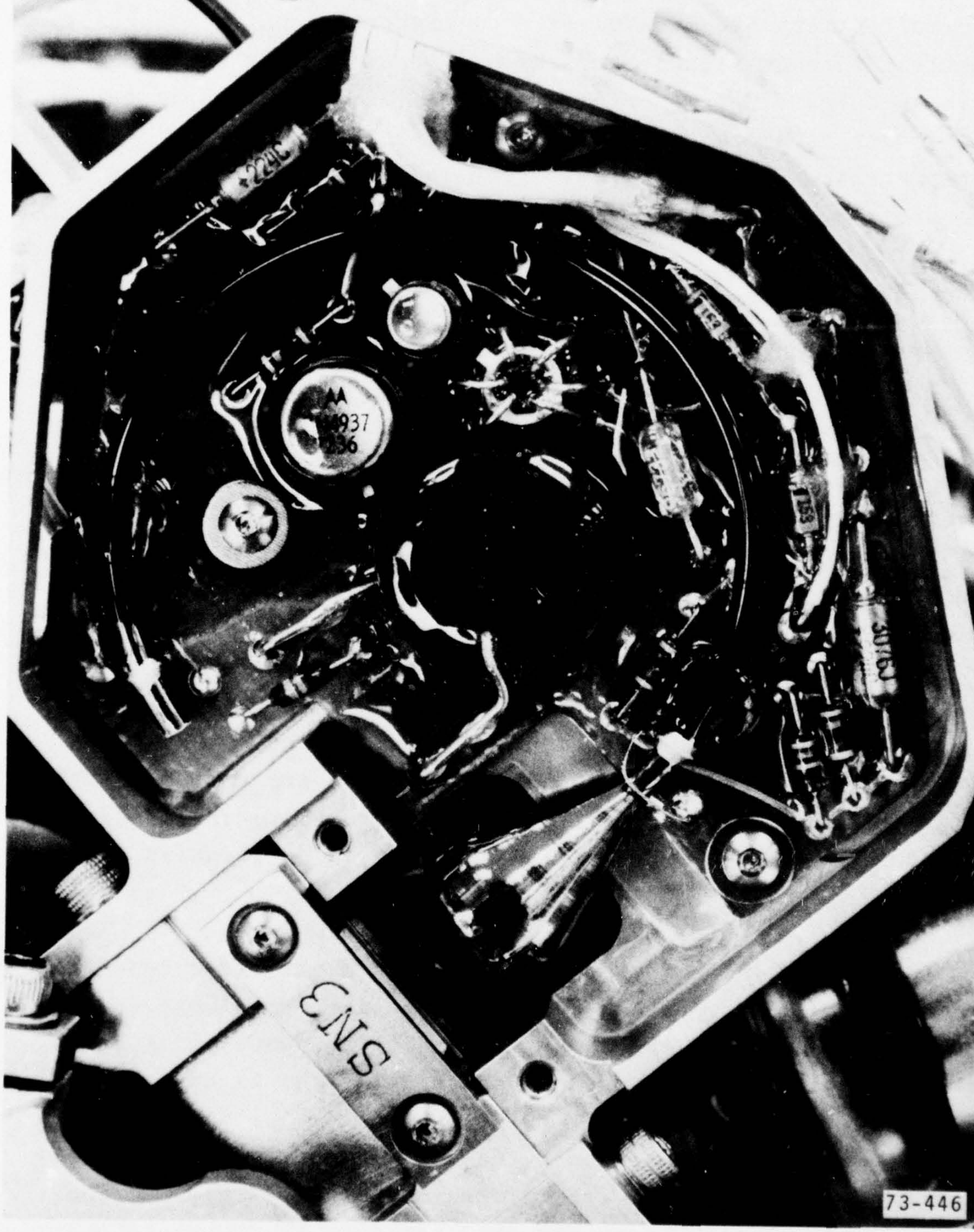

Figure 1-8 Detector Mounted to Printed Circuit Board

These tests were not designed to provide accurate photometric calibration. EUVS signal levels were converted to absolute values of solar flux by comparison with well-calibrated AFGL sounding rocket instruments launched during the AE missions.

1.3 INSTRUMENT ELECTRONICS

The instrument is divided into two functionally identical halves. Each half has its own aperture system, grating drive, and CEM high voltage supply. Insofar as possible, the instrument electronics preserve this functional independence, using separate telemetry and command systems for instance.

The instrument electronics are located in two areas: the pointed section of the EUVS and a spacecraft bodymounted main electronics box (MEB). These two packages are connected by a spacecraft-provided system of slip-rings and flex cables.

The basic EUVS measurement period is 0.5 of a second (8 spacecraft telemetry main-frames). A measurement consists of simultaneously integrating the digital output (accumulating the output pulses) of all detectors over a gated time interval of 380 milliseconds. The remaining 120 milliseconds is used for stepping gratings and/or apertures, and shifting data. During the integration interval, counts are accumulated in a separate scaler (capacity at least 14 bits) for each of the twelve modules.

The gain and discrimination level associated with the CEM amplifiers are chosen so as to produce a countable output for input pulses reflecting multiplier gains as low as 1×10^6. The amplifiers perform satisfactorily for a range of input pulses reflecting multiplier gains from 1×10^6 to 5×10^8. Dark count rates from the CEM detectors and amplifiers were below 0.1 false count per second in testing of the full EUVS system. The gain and discrimination level associated with the PMT amplifiers are chosen so as to

produce a countable output for input pulses reflecting PMT gains from 10^6 to 10^8.

The spacecraft main-frame consists of 128 eight-bit words at 16,384 bps. The frame repetition rate is sixteen per second. The EUVS assignment consists of four successive eight-bit words, plus a fifth located elsewhere in the frame. (The instrument has also been assigned seven subcommutated words, three digital and four analog.)

Main frame telemetry systems for the two halves of the instrument are functionally independent, with separate registers, buffers and controls. Detailed implementation of the telemetry system follows the guidelines of the RCA specification 2260216 and is recorded in the EUVS Interface Document.

Capabilities of the spacecraft command system are presented in RCA specification 2260216.

The available commands are of three general types:

A.	Minor Mode:	Bit-streams (32 bits)
B.	Major Mode:	Discrete pluses (logic level or relay-driving)
C.	Power:	Sustained DC power

EUVS normal operational modes are controlled by the minor mode system. This includes grating mode and position, aperture mode and position, and High Voltage (HV) level.

Major mode commands are used for HV on/off (relay driving), grating and aperture manual operation and any override to normal instrument operation.

Power commands are used to control the power status of the instrument. Separate power relays are not required in the instrument itself.

Each half of the instrument utilizes independent Minor-Mode and Major-Mode command systems. Regulated and unregulated power commands are common to the two halves; pulse load bus power commands are independent.

The instrument has two low voltage power supplies, one for detector circuitry and HV input (analog LVPS) and the other for digital circuits and memories (standby power), etc.

The analog LVPS uses regulated spacecraft power (-24.5 VDC ±2%). The digital LVPS uses unregulated spacecraft heater power (-32 VDC nominal) to allow standby operation with the spacecraft regulator off.

In addition, special pulse power lines are used for the main stepper motor power sources to reduce noise on the spacecraft instrument bus.

For full instrument operation, the average power consumption is 8.2 watts total at nominal -32 VDC supply voltage.

The instrument has two CEM high voltage power sources, each power supply serving five detectors, and a separate HVPS for the PMTs.

Each CEM supply has four main commandable output levels as, for example, output voltages of a positive 2600, 2850, 3100, 3200 and 3350 volts. Intermediate voltages can also be commanded by mixing the minor mode commands for two main levels. Each supply is equipped with a monitor indicating the output level of the supply to within 100 volts in the range of 2600-3600 volts.

Instrument design attempted to follow RCA 2260216 with regard to isolated signal, power, and chassis grounds. However, the particular problems associated with the EUVS slip ring interface required deviation. Therefore, we have tied regulated, unregulated, and chassis returns together at a single point in the EUVS pointed sections.

1.4 MECHANICAL DESIGN

Throughout this program emphasis has been placed upon the modular nature of the sub-assemblies of the instrument. The mechanical design reflects this intent. All items which are functionally common to the various monochromators, such as grating blanks, mirror blanks, aperture masks, exit slits, channel multiplier mounts, etc, are, in general, interchangeable. A design goal was to make the spectrophotometric modules as "plug-in" units. The replacable units would then be readily accessible for repair, testing or modification. This goal was only partially achieved: the modules exist as units, but assembly involves many modules together.

A cam and lever arm drive system is employed to generate the 128 positions of the scanning gratings. While overall stability and accuracy of the grating drive are important, a principal concern is regularity of step size. Individual grating steps do not deviate from their design value (1.5 arcminutes) by more than ±10% max, and total run-out error does not exceed one full step over the entire cam range.

A stow position is provided on the cam, outside the normal operating range. In this position, the cam captures the grating arm for launch. The normal cam follower is not in contact with the cam in stow, thus preventing possible damage.

The aperture masks consist of longitudinal sectioned cylinders, with appropriate apertures cut at 45° separation. The masks then rotate 45° between positions. The masks are driven by size 11 90° permanent magnet stepper motors (IMC 011-940) through a 2:1 gearing to achieve 45° steps.

The EUVS main structure is an electron beam-welded assembly of weight relieved magnesium alloy plates. Figure 1-9 shows the machined structural plates assembled with fittings just prior to welding.

Following welding, the structure is stabilized by cyclic immersion in liquid nitrogen, then live steam. This relieves welding stresses and stabilizes the structure for final machining. By the careful work of expert machinists, tolerances are held on the structure that can only be verified by optical means during instrument alignment.

1.5 ENVIRONMENTAL

The environmental design of the EUVS was a complex interactive effort among BBRC personnel working on the EUVS and the SPS; RCA personnel designing the AE spacecraft; and GSFC/AE Project personnel.

A detailed computer thermal model was generated at BBRC describing the EUVS, the SPS, and their interactions with spacecraft hardware. This model was compressed from 108 nodes to 37 nodes and transmitted to RCA for inclusion in the total spacecraft thermal model. Results from the RCA model were then returned to BBRC, where they were used as starting points to evaluate the 108 node model. After several iterations, a mutually acceptable thermal design was established. Orbital confirmation of the thermal design has been a RCA/GSFC activity, although EUVS thermistor data indicate informally that the design was very successful.

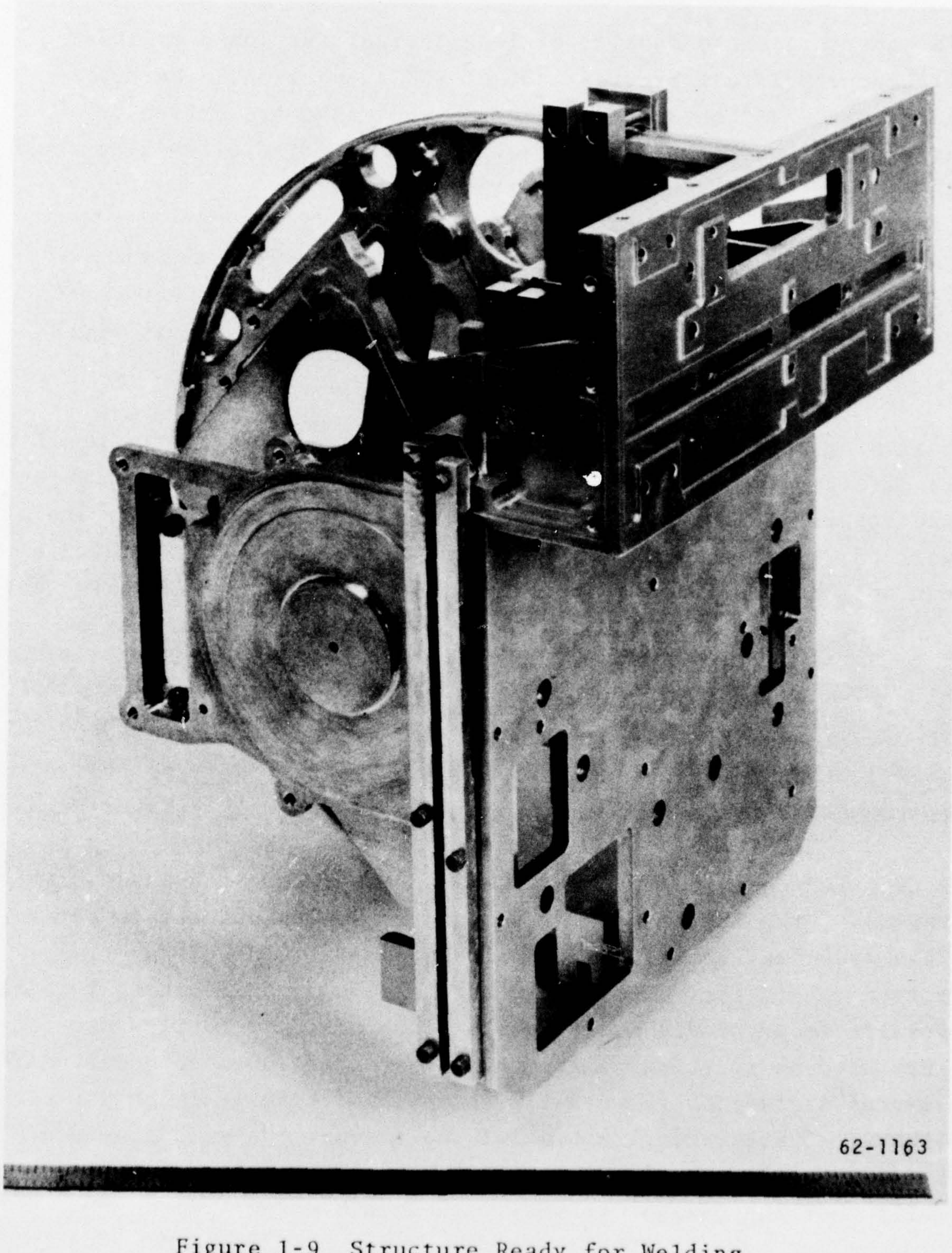

Figure 1-9 Structure Ready for Welding

Vibration stress design and analysis of EUVS was a similar interactive effort. The Pointed Section of the EUVS is supported by the trunnion of the Solar Pointing Platform (SPP). Thus the vibration environment of the EUVS is heavily controlled by the transmissibilities and resonances of the SPP. Lateral inputs are controlled by means of snubbers between the SPP and the launch adapter; thrust-axis inputs are heavily affected by bearing pre-loads and resounances in the main azimuth bearings of the SPP. These inputs were shifted and shaped by the SPP engineers to avoid the primary structural resonances of the EUVS which occur in the 80 - 100 hz region. We experienced no major problems in vibration tests or launch.

2.0 PROGRAM SUMMARY

The following sections describe the instruments we built, the schedule, and the highlights of the development effort.

2.1 INSTRUMENT BASELINES

Four EUVS units were built: the Design Verification Unit (DVU), the Protoflight model and two Flight models (FU-1 and FU-2).

The DVU is an EUVS unit that has been used to verify and correct the design of the EUVS, particularly in the complex areas of vibration and thermal analysis, and optical alignment and stability. It was fabricated to controlled drawings using good commercial quality parts in flight configuration. Parts, materials, and lubricants for the DUV are suitable for use in vacuum, and for exposure to prototype-level qualification tests. Gratings, mirrors, filters and detectors have been replaced by substitute elements, dummy units, or test fixtures for DVU evaluations. The DVU was also used in place of flight hardware during spacecraft thermal vacuum tests to avoid contamination of ultraviolet optics and detectors.

The Protoflight is a model of the EUVS having flight model dimensions, configuration and electrical characteristics, which meets proto-type level mechanical, electrical, environmental, and interface requirements. The Protoflight used pre-conditioned parts and was controlled by the same drawings which control Flight models.

After qualification testing, acceptance, and integration with the spacecraft, the Protoflight was returned to BBRC as Government Furnished Property for refurbishment and testing, including installation of calibrated optical elements and detectors. The Protoflight then was successfully launched 16 December 1973 on AE-C.

The Flight models meet all mechanical, electrical and environmental qualification requirements and tests, as well as all spacecraft interface requirements. The Flight models use preconditioned components and were fabricated, tested and calibrated in accordance with controlled drawings and procedures. In-orbit experience with the Protoflight resulted in some optical design modifications and optimizations of the flight units. Flight Unit #1 Pointed Section was launched on AE-E (19 November 1975) and Flight Unit #2 was launched on AE-D (6 October 1975).

2.2 PROGRAM SCHEDULE

BBRC activity on the EUVS program has encompassed over five years. Highlights of that schedule include:

Proposal Preparation	June 1971
Contract Start	19 October 1971
Design & Drafting	October 1971 - June 1972
Instrument Design Review	March 1972
DVU Fabrication	May - September 1972
GSE Fabrication	June - September 1972
Protoflight Fabrication	August 1972 - March 1973
Flight Unit Fabrication	April 1973 - January 1974
Protoflight Launch (AE-C)	16 December 1973
Flight Unit 2 Launch (AE-D)	6 October 1975
Flight Unit 1 Launch (AE-E)	19 November 1975

The first year of the program was very busy, including the total design effort and the fabrication of the DVU. The fabrication, alignment, photometric testing and spacecraft of the Protoflight unit filled the second year with activity. Funding levels and Delta vehicle slips combined to allow more schedule time for the Flight Unit alignment and calibration during 1974 and 1975. The time was profitably used to trim optical performance based on Protoflight orbital experience.

2.3 PROGRAM REVIEW

2.3.2 Design Phase

In the design phase, we were faced with several major challenges. Primary was the task of packaging twenty-four grating spectrometers into a cylinder only twelve inches in diameter and nine inches wide. The density of optical components was so high that we decided to eliminate most adjustments and place the burden of alignment tolerances on the mechanical design and the skill of our machinists. Final alignments would be achieved by lapping shims and mounting pads. Custom gratings, mirrors, and slits were specified also to be precise enough to require no adjustments. Because of the excellent work of our suppliers and our machinists, this approach proved successful.

Beyond the optical/mechanical design was the complication that both the spacecraft and the SPS were just starting design. The EUVS is mounted on the SPS inside the AE/Delta launch adapter. At launch, it actually protrudes into the booster half of the adapter. The vibration and envelope constraints were a major factor in configuring the EUVS.

All electronic signals between the EUVS Pointed Sections and the Main Electronics Box pass over a limited number of slip rings in the SPSP. Thus, our electronics design had to adapt to this interface. The most trouble some compromise was in the grounding of the Pointed Section: we spent many weeks on the DVU developing a noise-free power/ground arrangement.

Detector selection, evaluation, and mounting was a challenging but successful design task. Standard C-channel multipliers were baselined to reduce risk, but custom units were found necessary to give uniform response across the cone areas. To this end, we had the cones extended with a 3 mm cylindrical section, resulting in uniformities of better than 10% across the detectors.

An unpotted mounting arrangement was developed to avoid the stresses and HV problems inherent in solid-potted CEMs. The CEMs were mounted on three pads on their preamp boards and provided no problems in vibration or operation.

EMR 641-G-09 photomultipliers were selected for the two long-wavelength modules. The flight units proved to be stable, sensitive, and virtually trouble free.

The Ground Support Equipment was designed for manual operation because of the extensive computer-controlled testing at the spacecraft level. After assembly, the two units gave trouble-free service throughout the program.

2.3.2 DVU Development

The fabrication, assembly, and checkout of the DVU provided the first real check of our engineering. We found that machining accuracies would be achieved, that vibration and thermal designs were valid, and that the electronics could be made to work. We uncovered and corrected the mechanical interferences, assembly restraints etc. that just can not be seen on paper. Following our check-out, the DVU served as a substitute for the Protoflight during much of the checkout and test of the AE-C system. This proved critically valuable when a major contaminating accident occured in the AE-C thermal-vacuum testing - our orbital hardware would certainly have been damaged had it been in place. Because of this, the DVU was refurbished and updated to continue to substitute for the flight units during the AE-D and AE-E integration and T-V testing.

2.3.3 Protoflight Unit

The Protoflight Unit was the first EUVS to be carried completely through alignment and UV calibration tests. Combining this with the first integration of the AE-C spacecraft made for a very busy

time. Most worrisome was the short time available to analyze, repeat, and reflect upon the Protoflight UV calibration tests. Although we felt that the instrument was flight worthy, there were many areas deserving of more analysis. The Protoflight testing was a valuable learning experience for the Flight Units. We were able to incorporate changes in the test fixtures, the test plan, and the data analysis in time to give much more thorough data on Flight Unit optical performance.

2.3.4 Flight Units

The entire Protoflight experience was incorporated into the fabrication, assembly, and test of the Flight Units. Consequently, these units were completed in a smooth, orderly way, perturbed only by fiscal year funding restriction.

Most importantly, we were able to run each of the Flight Units through UV calibration testing many times. During the tests we verified the photometric stability of the optics and detectors, corrected minor alignment problems, and eliminated some potentially serious sources of scattered light. This testing was of sufficient importance that we altered the planned launch order of the two units to put the "best" unit (FU-2) on AE-D while modifications were being made to FU-1. At the launch of AE-E, FU-1 was at least as good as FU-2 had been, and also more thoroughly evaluated.

The launch preparation of AE-D and AE-E provided several moments of excitement for the EUVS. Following the unpacking of the AE-D spacecraft at the Western Test Range, a mysterious contamination was observed on parts of the spacecraft structure. The EUVS contamination monitor mirrors were removed and flown to Boulder. In an all-night test effort, they were found to be unaffected, thus assuring us that the internal optical region of the EUVS was not contaminated. (The problem was condensation due to unloading on a cool, moist night.)

With the AE-D spacecraft on the booster, in the tower, we found the EUVS detector-preamps measuring the oscillator frequency of one of the AE low voltage power supplies when the maximum S/C load was applied. We probed our power lines while in the tower to track down the cause. Apparently pulses from the switching regulator were coupling into the unregulated bus when a large amount of regulated power was drawn. The problem was not noticed with the back-up power system, and a decision was made to launch as-is. Following launch, we flew to RCA to explore the AE-E spacecraft for similar problems. The same phenomenon occured, but at a level below our detection threshold. To increase our margin of safety, ferrite beads were added to our power lines to filter the AE power system spikes. No further problems were seen on AE-E.

2.4 ORBITAL PERFORMANCE

2.4.1 General

All instrument operation and data reduction has been handled at AFGL. Thus, we at BBRC have only limited knowledge of the scientific and technical performance of the EUVS instruments post-launch. In particular, our concern has been directed entirely at the malfunctions rather than the successes. We have worked with only three partial instrument malfunctions, and understand that in other aspects, the instruments have succesfullly met their orbital performance goals.

2.4.2 Protoflight

The Protoflight instrument exhibited two problems, First, one of the aperture masks did not center properly as it stepped from one set of monochromators to the other. The varying vignetting of this aperture made absolute photometry impossible, but the vignetting was small enough that occultation/absorption measurements

were still possible. Laboratory simulations uncovered the fact that there was extended "ringing" in the mask/stepper motor system for some of the stepper motors. We lightened the masks and extended the motor pulse lengths on the Flight units to overcome the problem, and tested the flight units extensively before and after all environmental tests pre-launch.

After several months of operation, one coil on one of the grating drive stepper motors failed to fire suddenly. We assume that an electronic part died, a wire broke, or some other single event occurred. By commanding the motor to skip over the inactive coil, it was possible to achieve full spectral coverage, save for every fourth step, in a "struggle scan" mode. This caused changes in operational programs and data reduction, but still allowed valuable spectra to continue to be taken.

We understand that the Protoflight has maintained its operational ability without further incident for the 2 3/4 years it has been in orbit.

2.4.3 Flight Unit #2 (AE-D)

Within a few weeks after launch, one of the aperture masks on FU-2 exhibited a malfunction which we analyzed as being a binding of gears in the mask drive system. We are unable to determine the cause, but suspect that the launch vibration may have affected the meshing of the two gears, or that perhaps some particulate matter became enmeshed in the gears. We were able to restore the mask to one of its positions, and left it there early in the mission for fear of latching in an unstable position. Before we began to re-investigate the problem, the AE-D spacecraft was catastrophically lost.

2.4.4 Flight Unit #1 (AE-E)

To our best understanding, FU-1 has met its performance goals without problem for the nine months it has been in orbit.

3.0 COMMENTS

The overall EUVS program was a cooperative effort. AFGL provided the scientific guidance and optical design oversight. GSFC supported other design and analysis efforts and day-to-day program planning. RCA, as spacecraft contractor, provided working interface information and managed the separate BBRC contract for the Solar Pointing Subsystem. The individual people at each of these centers provided valuable assistance to our efforts, and we acknowledge their help.

Through the efforts of Dr. Hinteregger and Mr. Chagnon at AFGL, and D. Grimes, J. Findlay and R. E. Donnelly of AE-Project we were able to focus our entire program on the three main priorities of performance, schedule, and cost. We were able to develop open communications and trust at every level, and to avoid any dissipative struggles amongst ourselves. This mutual cooperation made our efforts much more enjoyable, and contributed to a strong personal involvement of all of the BBRC engineers and technicians on the program.

The entire AE-Project team at GSFC provided excellent support to the EUVS Program. Particularly in the integration, test, and launch activities we were impressed with the knowledgeable support and cooperation we received.

Finally, we gratefully acknowledge Dr. Hinteregger's personal contribution to our contract effort. Throughout our effort he was an invaluable source of technical support and inspiration, without which we could not have achieved what we did.

4.0 REFERENCE DOCUMENTS

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